The Factory is Virtual ……The Savings are Real

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Introduction

Modeling and simulation of manufacturability and supportability have been used to different degrees in the JSF, AAAV, DD-21, Future Frigate, Virginia Class Submarine, and many lifecycle extension programs. The use of digital manufacturing tools has resulted in innovative manufacturing techniques to significantly reduce tooling cost and to create modular build and test methodologies. Supportability studies have impacted designs to reduce lifecycle costs by reducing manning levels, by eliminating the need for special tooling and by avoiding un-maintainable conditions. The number of physical product prototypes and tooling mock-ups has been reduced by proving out tooling and processes in the 3D digital environment. Based on the learning curves experienced in the digital manufacturing environment, initial physical prototype builds have been completed with significantly fewer labor hours than have historically been required, and without the delays and costs associated with missing un-buildable conditions before the physical build. Reductions in non-conformances during the initial build versus previous programs have exceeded 90 percent. The modeling and simulation efforts of the IPT during the design and engineering, manufacturing and development phases are now being used for generating electronic 3D work instructions and serve as the build-to authority for the shop floor. The same models and similar processes can be utilized for service and maintenance processes.

The "next step" is to integrate the pre-planning and process planning activities as the front end of the contiguous digital workflow, and utilize the modeling and simulation solutions for the 'process verification' step. The capture in a digital format and reuse of the corporate manufacturing knowledge base is now practical. A product, process and manufacturing resource (PPR) database maintains the relationships between each process activity and the product data and resource data required to accomplish that activity. It must handle the variants possible including the differences for each tail number or hull number. Effectivity must be managed for not only product data, but also process and resource data. Interfaces with existing legacy CAD, PDM, manufacturing execution and MRP/ERP systems must be established within each corporate IT environment. The capability and benefits that have been achieved in the automotive industry with a common, shared PPR database for conceptualizing, designing, planning, validating, optimizing and executing a lean production

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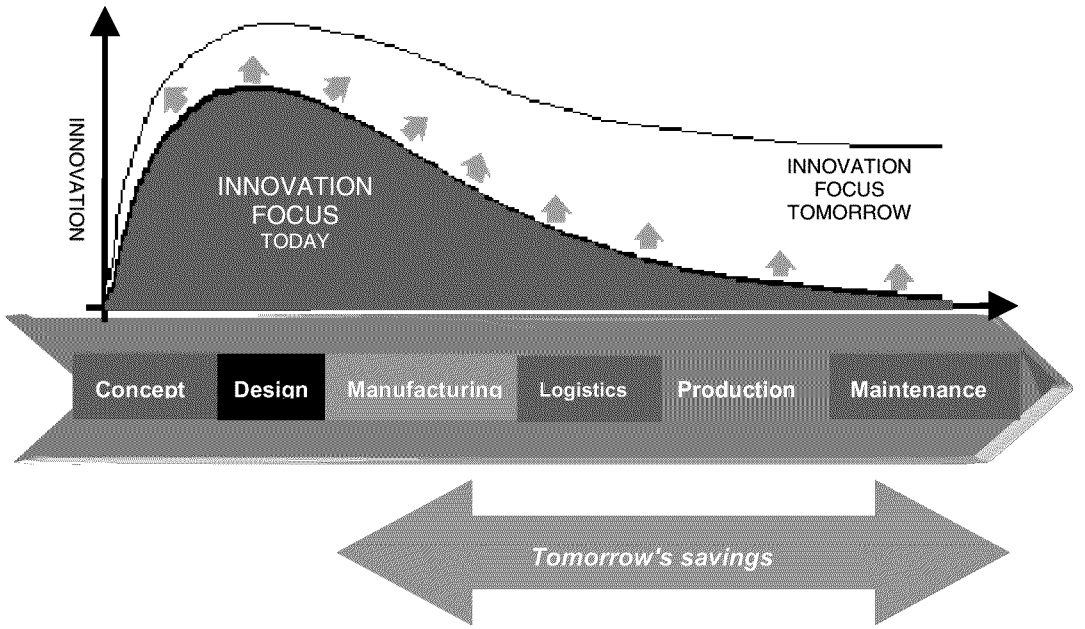
system are well documented. Early adopters within the defense industries are now applying these lessons learned in their operations.

Innovation Focus Moves to Manufacturing & Life Cycle Support

Most major industries have moved to 3D CAD for product design and have realized the savings in this portion of the product realization cycle.

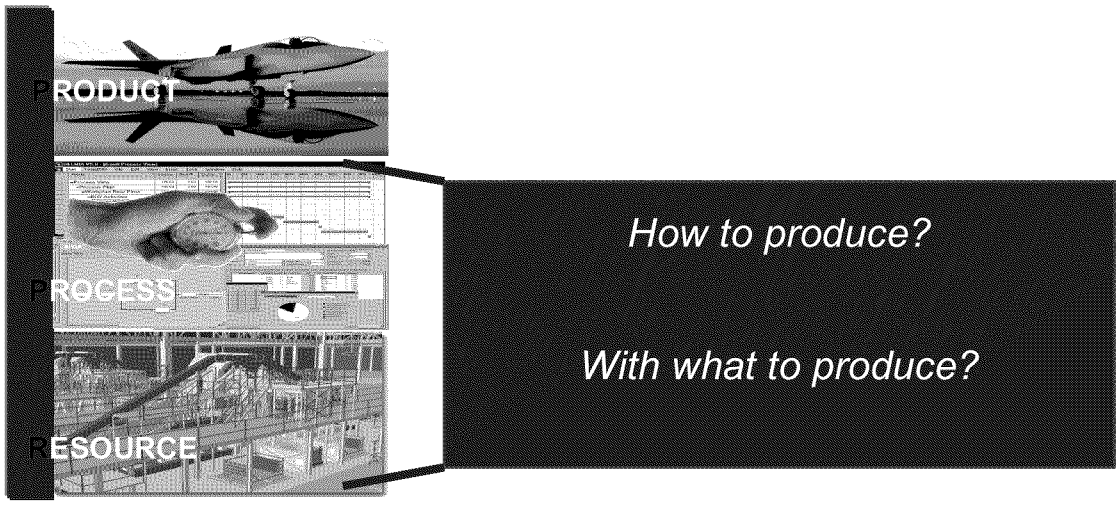


They are now beginning to leverage this investment in 3D CAD downstream in planning, validating and executing their manufacturing plan for these new products. The ability to perform thousands of iterations of different manufacturing and maintenance concepts in the digital environment without the cost and time delays associated with physical mockups has enabled manufacturers to realize the benefits from:

- Design for fabrication
- Design for assembly
- Design for maintainability
- Factory layout and flow simulation
- Innovative product designs and manufacturing processes
- Re-engineering the processes and flow for lean manufacturing
- The generation of simulation based, 3D work instructions / training

The Digital Factory

The Digital Factory environment uses the input from the CAD and PDM systems on ***What to produce,*** or the Engineering Bill of Materials and uses digital models of the manufacturing resources such as labor, tools, fixtures, plant layout which is the ***With what to produce*** so that the planners and manufacturing engineers can design the most efficient production system, and determine ***How to produce***.



The Digital Factory provides the collaborative environment for the Integrated Product Teams to concurrently develop the product designs, manufacturing tooling and processes, as well as, maintenance tooling and processes. This parallel development of product and process decreases the product development cycle and the ability to work with digital mockups of the product and tooling enables the process engineers to begin at the conceptual phases and constantly refine their processes as the designs mature. By proving out their tooling concepts and manufacturing processes in the digital environment they prevent costly engineering change orders caused by un-buildable conditions during the product launch. Using the 3D simulations developed during the process validation efforts to create 3D work instructions to the shop floor greatly enhances the communication of the design intent of the manufacturing engineer to the mechanics, and minimizes their learning curve.

The Shared Product, Process and Resource database.

Up to 60 percent of the historical effort of using modeling and simulation in manufacturing has been gathering the ***correct*** information to use in the models. Now that the Product, Process and Resource (PPR) database is inter-connected to the enterprise's PDM and CAD data, this problem is minimized for the product and tooling data. Only recently has the capability existed to maintain a process centric database that maintains the linkages for each process activity, and the product data the goes into and out of that process step, as well as, the manufacturing resources that are required by the process activity. This database also maintains the manufacturing related attributes associated with the product, process and resources and a library of best practices. Then the initial conceptual process plan can be developed well before any CAD data is available, reusing best practices wherever possible. This conceptual plan can be linked to existing manufacturing resources. Then when the CAD

data for the product is available a 3D verification of the manufacturing concept in the context of the manufacturing resources and product design can be completed quickly and accurately.

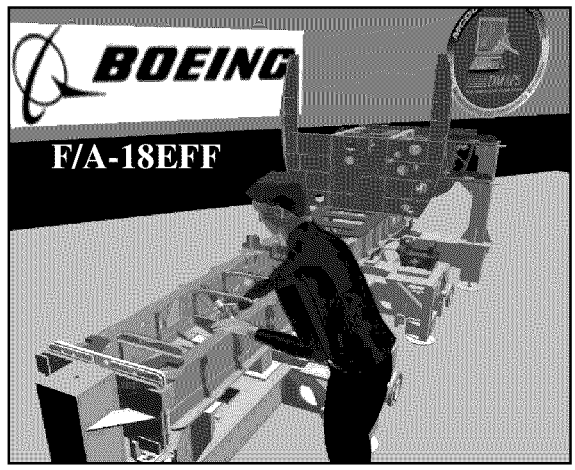
From Concept Design Through Production Ramp Up

As the product, tooling and process designs mature they can be validated against the constraints and the manufacturing cycle times and costs accurately determined. Ergonomic simulations will verify that the tasks can be accomplished safely and within the time desired. Tooling concepts are evaluated and optimized. The plant layout and material flow evolves from the manufacturing concepts and can be extracted from the PPR database to conduct trade studies of alternative manufacturing concepts, plant layouts, production rates and manning levels. Once the production system is finalized, these models can be used to document and publish 3D work instructions to the mechanics on the shop floor and in the field for maintenance activities.

Boeing has realized significant saving from Digital Manufacturing

Boeing's Commercial, Space, and Military/Defense business units are using DELMIA virtual manufacturing, digital pre-assembly and discrete event simulation tools, to significantly lower production cost and cycle-time on a number of existing, as well as, new products/programs. Critical to successfully supporting these product/programs is the ability to identify potential production problems and design deficiencies during the product development stage prior to final design commitment. Also critical is the ability to accurately assess tooling, support equipment and factory requirements early on. Boeing utilizes the digital manufacturing tools to provide an effective means of improving Boeings product development, production, and factory change over processes.

Assembly Simulation

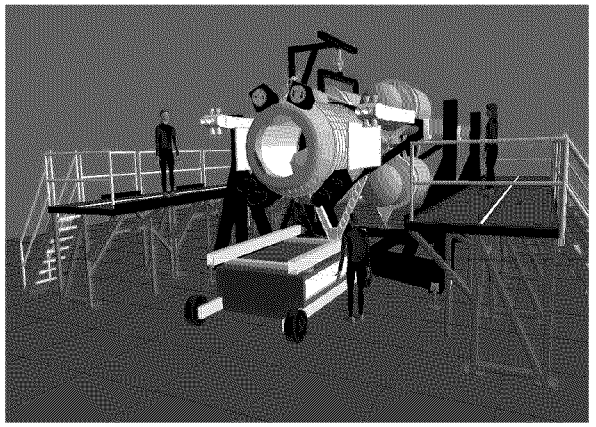


Assembly simulation has been used on many aircraft and aerospace programs such as the space shuttle, UCAV and the F/A-18EFF pictured above. Significant benefits have been realized in the areas of:

- Validating Design/Assembly Integrity Prior to Commitment
- Validating Operation Sequences & Tooling Concepts
- Identifying Assembly Anomalies
- Driving & Validating Design Release Schedule
- Enabling Optimization of Assembly Processes
- Reducing Downstream Production Planning (Assembly)
- Creating Consistent Virtual/Simulation Based Work Instructions
- Capturing Best Assembly Practices

Savings in assembly hours in the range of 40-60% have been realized across multiple programs. Cost avoidance due to interferences eliminated, ergonomic problems and incorrect assembly sequences have resulted in 20-55% savings over historical performances.

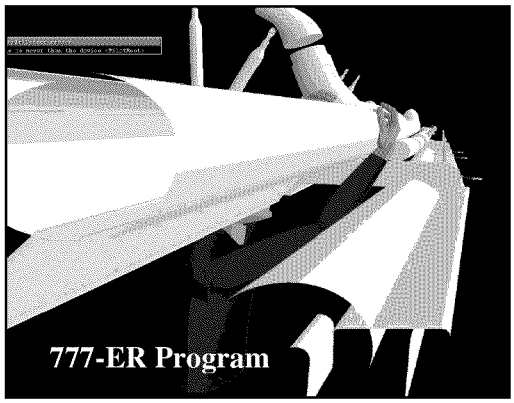
Resource Planning and Flow Simulation



The planning and simulation of factory operations for military, commercial and space programs has provided the capability to develop and prove out lean manufacturing operations first in the digital environment, before committing time and money to the physical manufacturing facilities. These same simulations have been used to generate 3D work instructions for the mechanics on the shop floor. Some of the benefits realized include:

• Production Drawing Changes	40%	Reduction
• Tooling Design & Fabrication	50%	Reduction
• Planning Hours (assembly)	25%	Reduction
• Assembly Hours & Cycle time	30%	Reduction
• Technician Errors/Reworks	50%	Reduction
• Planning Errors/Reworks	50%	Reduction
• Technician Preparation	15%	Reduction

Ergonomic Analysis



Ergonomic Analysis has been applied to numerous commercial, military and space related manufacturing and maintenance tasks. They have dealt with accessibility problems, serviceability with the required tools, human factors and employee safety. Some of the benefits derived from these studies include:

- Identifying Hazardous Operations (Hardware / Personnel)
- Validating Serviceability/Operations
- Ensuring Accessibility During Assembly / Test / Operation / Maintenance
- Highlighting Potential Tooling and Equipment Requirements

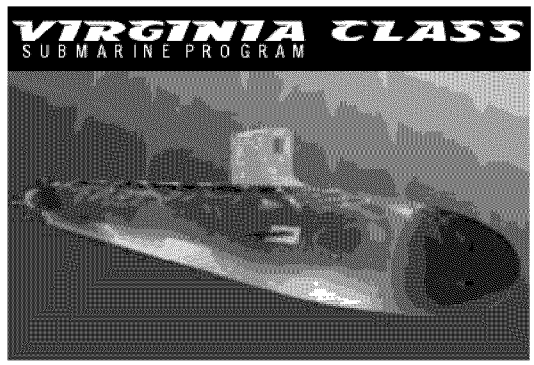
Lockheed Martin - "The factory you see may be virtual, but the time and money savings are real."

This simulation is for the removal of the engine on the prototype JSF aircraft. Lockheed Martin made extensive use of manufacturing and maintenance simulations during the development of their contract winning design. This simulation was also used to brief the crew that installed the engine into the aircraft. The first actual installation was done in three hours, which is very quick, and the crew credited the simulation for part of their thorough preparation. Since simulation enabled the team to consider maintenance issues very early in

the design cycle, there were numerous instances where the maintainability studies influenced the design of the aircraft.

Simulation was also used for program a large Gantry Automated Drilling System for drilling and milling the wing carry-through section. Because the wing carry-through section is the aircraft's biggest and most critical structural component, the simulation show an entire section of the factory including all the material handling that would be required. Through the use of simulation they were able to develop a process that reduced the task from four persons for three days, to three people for 30 minutes.

General Dynamics Electric Boat – "Manufacturing Efficiencies Previously Achieved on the Third Ship Set are now Realized on the first Ship Set"



Starting with the DARPA funded Simulation Based Design project during the second half of the 1990s, General Dynamics Electric Boat has adopted a Design / Build philosophy that is heavily dependent on 3D, physics based simulation. Using assembly planning and simulation to create innovative manufacturing practices they feel that the can reduce the Design / Build time from 14 years to 7 years. They expect that the revised manufacturing processes will reduce the cost of the submarine by approximately 30 percent. One of the savings is a 50 percent reduction in change orders since they have already proven out the fabrication and assembly processes in the digital environment. This will also enable them to have the manufacturing efficiencies previously achieved on the third ship set on the first ship set.

Conclusion

A great deal has been accomplished through the heretofore, intermittent use of manufacturing modeling and simulation. Because of the cost involved in gathering and verifying the data to be used in the simulations, and the lack of 3D data in some industries, it has not yet become the way of doing business every day for most defense manufacturers. As the industry moves to 3D design and the digital manufacturing solutions become easier to integrate into the knowledge management and IT environments, the productivity of the users increases dramatically. The ability today to share a common database of product, process and resource data across the enterprise significantly increases the productivity of the manufacturing engineers. The future savings from the virtual factory will provide the competitive edge in the aerospace and defense marketplace.

Paper #6
Discussor's name G. M. Appleyard
Author J. M. Caddick, R. G. Brown

Q: 1) Are the quoted manufacturing cost/time savings achieved with the same manufacturing/assembly techniques/concepts?
2) Please can you comment on any synergies you perceive between advanced manufacturing/assembly techniques/concepts and Virtual Manufacturing simulation?

A: 1) Basic methods used are the same. However, simulation enables significant benefits by providing assembly sequencing and optimization.
2) DFA (design for assembly) techniques are validated through simulation, thus tools complement one another.

Discussor's name S. Kaun
Author J. M. Caddick, R. G. Brown

Q: Are there any interfaces available to transfer the geometrical data from the various PDM systems to the DELMIA tools? Did any difficulties appear when transferring the geometry from UNIX to the NT world?

A: A standard interface to the ENOVIA VPM exists. Customer interfaces to Metaphase and iMAN have been developed. Since every PDM installation is unique, some customization is required. All DELMIA applications run on NT and can access the CAD data from UNIX based CAD systems.

Discussor's name M. Bergamasco
Author J. M. Caddick, R. G. Brown

Q: For assembly testing and/or ergonomics studies, does you company use specific man-machine interfaces such as haptic interfaces?

A: Drivers exist for data gloves, pinch gloves, and major magnetic motion sensor systems. Users can use the available tool kit to develop their own drivers for haptic devices.